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Electron injection at shocks: Transition from stochastic shock drift acceleration to diffusive shock acceleration

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The acceleration of high-energy particles is common both in heliophysics and astrophysics. The diffusive shock acceleration (DSA) process has been the standard mechanism for particle acceleration at collisionless shock waves. It is, however, well known that DSA cannot explain the acceleration of low-energy electrons because of the lack of efficient scatterers. We have proposed stochastic shock drift acceleration (SSDA) as a plausible mechanism to resolve the problem of electron injection [Katou & Amano, 2019]. The energy gain mechanism of SSDA is essentially the same as the conventional shock drift acceleration (SDA), but the presence of stochastic pitch-angle scattering makes the acceleration more efficient. Good agreements between theoretical predictions based on SSDA and in-situ observations by Magnetospheric MultiScale (MMS) spacecraft have been reported [Amano et al. 2020]. Furthermore, electron acceleration signatures found in fully kinetic Particle-In-Cell (PIC) simulations have also been found [Matsumoto et al. 2017, Kobzar et al. 2021]. Motivated by these previous studies, we have developed a theory that can consistently predict the energy spectrum for sub-relativistic and relativistic energy ranges. We find that the spectrum at the sub-relativistic energy produced by SSDA is steeper than the standard DSA prediction. As the particle energy increases, the particle acceleration mechanism may smoothly transition from SSDA to DSA. We find that the electron injection scheme through SSDA occurs preferentially at shocks with higher Alfven Mach numbers defined in the Hoffmann-Teller frame.

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